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Geotechnical aspects of domestic on-site effluent management systems

J. H. WHITEHEAD[1] AND P. M. GEARY[2]

[1]*Department of Geology, University of Newcastle, NSW 2308, Australia.*
[2]*Department of Geography and Environmental Science, University of Newcastle, NSW 2308, Australia.*

Geotechnical aspects of domestic on-site effluent systems (septic tanks) and their impact on groundwaters are discussed and the limited relevant literature is reviewed. While there are few Australian case studies, the early stages of an ongoing study at Dodges Ferry, Tasmania, show a connection between shallow aquifer quality, number of residences and domestic on-site wastewater disposal practices. Of 26 groundwater samples analysed, a number fail to meet established criteria for potable use. Most samples were highly or very highly saline. This renders them unpalatable and has an adverse impact on vegetation if the water is used for irrigation. Several samples had pH less than 6.0 and those taken from shallow wells were discoloured by leached soil organic matter. Elevated nitrate levels, an indicator of contamination by sewage effluents, were found at nine locations and these were usually associated with small clusters of residences. One very high sample was clearly contaminated by effluent from an adjacent on-site wastewater disposal system. One odorous, black organic seep was found at the foot of the dunes backing a bathing beach and this gives cause for concern that failing on-site wastewater disposal systems are contributory to reduced bathing water quality. Faecal coliforms and *Escherichia coli* were not found, even in samples with the highest nitrate concentrations, suggesting that residence time has been sufficient for bacterial die-off. Contamination of shallow aquifers is greatest where there is a high density of residences with small lots.

KEY WORDS: groundwater quality, pollution, unconfined aquifers, wastewater.

INTRODUCTION

For most of the Australian population living in urban areas, a reticulated sewerage system is provided for the removal and treatment of domestic wastewaters. In non-sewered urban and rural residential developments, these wastewaters are usually treated and disposed on-site. The traditional method is an all-purpose septic tank, where partial treatment of the raw waste is followed by absorption or absorption/transpiration into the unsaturated zone of the soil (Geary & Gardner 1996).

Aerobic wastewater treatment systems, which provide extended aeration prior to disposal by spray or drip irrigation, are becoming a popular alternative. Increasingly, dry or wet composting systems are also used. Other systems rely on the properties of soil or rock materials for filtration and nutrient removal.

Such on-site wastewater treatment systems provide for more than two million people, some 12% of the Australian population. They are common in the developing outskirts of large cities, in small towns and villages, in rural/residential lifestyle developments and in isolated residences. In New South Wales alone, there are approximately 250 000 on-site systems which utilise septic tanks (Geary 1994). It is estimated that some 130 000 of these dwellings are connected to mains water supply with the remainder relying on rain storage or groundwater supplies (Patterson 1993).

Water usage, and consequently volume of effluent, is generally higher where mains water is available and this exacerbates wastewater disposal problems. Additionally, there are more than 20 000 aerobic wastewater treatment systems in New South Wales and this number is steadily increasing. Many on-site systems, intended as short-term expedients, have become permanent features as the promised reticulated sewerage has not been provided. Furthermore, the population relying on these systems is rising, as more people move to rural and urban fringe locations.

A number of surveys (Geary 1992, 1993; O'Neill *et al.* 1993; Jelliffe 1995a) have indicated that a large proportion of on-site systems fail. Failing systems and inadequate effluent disposal have serious environmental health implications and contribute to nutrient-related water-management problems. There is concern about effluent impacts on both surface water (Beard *et al.* 1994) and groundwater (Hoxley & Dudding 1994; Ivkovic *et al.* 1998; Whitehead & Associates 1998) in a number of Australian regions. Nevertheless, relatively little has been published about the nature and extent of on-site wastewater impacts.

The public health and environmental implications of on-site system failures have been brought to the fore with concerns over nutrient loadings and algal blooms, the 1996 outbreak of hepatitis in Wallis Lake, New South Wales (Brooker 1999), and the 1998 occurrence of *Cryptosporidium* and *Giardia* in the Sydney water supply. There is a need to apply scientific and engineering skills to the design of on-site systems and this has created opportunities for geoscientific input (Whitehead & Geary 1996).

REGULATORY ENVIRONMENT

Domestic wastewater management has generally been administered at local level in Australia, with state government agencies being responsible for developing appropriate guidelines. This has resulted in wide variations in approach to site assessment and system design, as each local authority has developed its own requirements. While local knowledge is important with respect to both ground conditions and system design, the lack of standardised procedures has led to many inconsistencies in approach, system sizing and, consequently, performance.

Significant advances have been made with the release of revised guidelines and codes of practice in a number of states: South Australia (South Australian Health Commission 1995); Tasmania (Australian Institute of Environmental Health 1998); New South Wales (Department of Local Government 1998); and Queensland (Department of Natural Resources 1999). Each of these codes requires rigorous evaluation of ground conditions. The current Australian Standard AS 1547 (Standards Australia 1994) requires a full evaluation of the land capability of a disposal site. This includes an assessment of soil texture, slope, flooding frequency, depth to bedrock and to groundwater. However, this document is not without shortcomings.

The Australian Standard requires, where possible, the use of a clean water percolation test by either a falling head or constant head method. Alternatively, a field soil texture determination may be used for estimating permeability. The suitability of clean water to replicate effluent in permeability tests may be questioned. Furthermore, it has been demonstrated (Geary 1994) that there is a poor correlation between percolation test results and permeability (K_{sat}) determined in the field using a constant head permeameter. The percolation test is not considered a reliable means of determining soil permeability.

It is known that the organic content of the effluent causes clogging of the soil (Healy & Laak 1974; Kristiansen 1982). As a result, the long-term acceptance rate of the soil is much lower than the measured permeability. The Australian Standard makes use of a curve based on very little empirical Australian data to determine the long-term acceptance rate of the soil. The limitations of this approach are further discussed by van de Graaff and Brouwer (1999).

AS 1547 is currently under review and is due to be released shortly as a combined Australian and New Zealand Standard AS/NZS 1547 (Gunn & Devine 1999). Both this revised standard and the more recent state government guidelines have moved away from the prescriptive approach to site assessment and system design, and have adopted a performance-based approach. In so doing, they have replaced permeability testing with the determination of long-term acceptance rate from soil texture, thus relying more on the professional judgment of the tester.

This should ensure, with time and experience, that more appropriate loading rates for specific soil conditions can be determined. Adjustments can be made in the light of local experience gained from long-term performance of disposal systems. These changes bring the new standard into line with approaches already successfully adopted in New Zealand and the United States.

GEOTECHNICAL ASPECTS OF SITE ASSESSMENT

Site investigation at both subdivision and single-lot scale requires appropriate assessment of bedrock and surficial geology, soils and terrain. Geomorphological aspects of sites are significant in terms of drainage, seepage of water onto the site, flood potential, discharge to surface waters and recharge of groundwaters. Seasonal changes in groundwater level and absorptive capacity must be evaluated, together with evaporation and transpiration. Site assessment needs to take into consideration perched water-tables, weathering of shallow bedrock, the nature of surficial and deep aquifers and their exposure to contamination. An appreciation of effluent and soil-water chemistry and nutrient and pathogen transport is called for. Opportunities to exercise groundwater-modelling skills might arise in regional studies.

Many Australian soils have duplex profiles, with dispersive clays of low absorptive capacity at depth. The sodium loading of effluent often significantly reduces permeability of dispersive B-horizons (Patterson 1993). Other chemicals entering the household waste stream can also affect the soils to which the effluent is applied. Phosphorus from laundry products and foodstuffs (Patterson 1998) is easily sorbed onto soil. While it is not easily leached out, it can move with eroded soil particles. Furthermore, once soils can no longer sorb phosphorus, there is greater potential for adverse nutrient impact on receiving waters (Martens & Geary 1999).

A number of groundwater-modelling studies relating to on-site wastewater contamination are to be found in the American literature. Anderson *et al.* (1987) estimated that the high density of on-site systems and typical subdivision sizes in Florida would cause the 10 mg/L nitrate in groundwater standard to be exceeded at allowable housing densities for a 50 acre (~20 ha) subdivision. Reneau *et al.* (1989) pointed out that most health-related studies of water quality had been centred on faecal indicator bacteria, but that the transport of viruses through soils might be dissimilar. They also identified significant phosphorus removal within a short distance from the on-site system, while nitrate mobility was much greater. Bechdol *et al.* (1994), investigating potential groundwater contamination by viruses from septic system discharges in Rhode Island, predicted that wells were at risk when septic systems were located 30 m upgradient.

Scandura and Sobsey (1997) noted that factors influencing pathogen transport and survival from on-site wastewater systems remained inadequately characterised. Their investigations in sandy coastal aquifers of Northern Carolina demonstrated that virus detection was more associated with proximity to septic effluent distribution lines than with distance from wastewater source, drainfield soils, high groundwater pH and high water-tables. They also found a weak correlation between levels of viruses and faecal coliforms, supporting earlier evidence that bacteria are not reliable indicators of viruses in contaminated groundwaters.

In Australia, Beavers and Gardner (1993) have developed a predictive model of viral transport through soils. They found temperature, pH and microbial activity to be the major factors that influence the survival and transport of viruses and bacteria. The model can be used to determine setback distances for the prevention of viral contamination by measurement of temperature, hydraulic conductivity, hydraulic gradient and effective porosity. Gerritse (1993) has developed a model to predict travel times of phosphate in soils at a wastewater disposal site, based on his work in Western Australia. Another Australian model was developed by Jelliffe (1995b) for predicting stormwater quality from unsewered development and for determining the optimum housing density.

GROUNDWATER IMPACTS AND MINIMUM LOT DENSITIES

The Rural Water Corporation of Victoria has investigated the impact of septic-tank effluent on groundwater receptors in the Murray Basin at Benalla, Victoria (HydroTechnology 1993). This study identified septic-tank effluent as the cause of groundwater nitrate–nitrogen (nitrate–N) levels higher than the World Health Organisation standard of 10 mg/L. Bacterial contamination was also identified across the study area, posing a significant health risk to groundwater users. More than 15 septic tanks per km^2 are cited as the primary cause and the study notes that at least 114 Murray Basin towns in Victoria have densities above this figure.

Both the Benalla study and a further study at Venus Bay, Victoria are reported by Hoxley and Dudding (1994). At Venus Bay a shallow aquifer provides water supply for, and receives septic tank effluent from, a community of up to 3000 during the peak holiday season. House lots are small, on average about 800 m^2, and each typically has both a septic tank and a bore, often within 10 m of each other. There was no significant pollution of the aquifer by nitrogen, with nitrate levels not exceeding 8 mg/L. The shallow aquifer was, however, contaminated with significant levels of faecal bacteria up to 500 m distant from the area of septic tanks.

A more recent study of groundwater quality from 42 bores in the Piccadilly Valley, South Australia (Ivkovic *et al*. 1998) identified nitrate levels above background, though only in one case exceeding the 11.3 mg/L nitrate–N (equivalent to 50 mg/L nitrate) National Health and Medical Research Council / Agriculture and Resource Management Council of Australia and New Zealand (NH&MRC/ARMCANZ) drinking-water guideline. There has, however, been an increase in nitrate concentration in 54% of the bores over the period 1979 to 1994. Faecal indicator bacteria were detected in 19% of the bores, with leaking septic tanks the most probable source.

Rural residential development is occurring preferentially at higher elevations around the Piccadilly Valley, coinciding with recharge areas which appear most vulnerable to contamination from leaking septic tanks. The study recommends monitoring of groundwater quality and emphasises the need to understand the influences of natural hydrogeological and geochemical processes, especially recharge, in order to protect the resource.

Two further studies are currently underway in Tasmania, one at Lauderdale (Cromer 1998) and one at Dodges Ferry. The latter is reported here.

DODGES FERRY CATCHMENT MANAGEMENT AND GROUNDWATER MONITORING

In 1998 a three-stage catchment management and groundwater monitoring program commenced in several small unsewered communities in and around Dodges Ferry, approximately 35 km east of Hobart, Tasmania. Dodges Ferry and nearby Carlton are holiday-shack areas that have recently become more permanently occupied. Domestic-wastewater disposal in these communities, where lot sizes are typically less than 800 m^2, is on-site in sandy soils. The performance of such systems is variable, with some giving the appearance of working well while others clearly require upgrading. Sorell Council, the local authority, is concerned that with shallow water tables and permeable soils in some areas, there is potential for groundwater and surface-water contamination. The area is along the coastal zone and is used for activities such as swimming and surfing particularly in the summer months.

Here we present the results of the first stage of the groundwater monitoring program around Dodges Ferry. The aim of the study was to identify impacts arising from on-site wastewater-disposal systems in relation to groundwater and surface drainage. The initial survey revealed low levels of bacterial indicators in bore water, but some high nitrate concentrations. These were usually associated with clusters of houses and several high-risk areas were identified. It does appear that the failure of on-site systems is affecting, to a limited degree, the quality of shallow groundwater in the area.

A recent survey of recreational water quality at swimming beaches around Dodges Ferry reported higher than desirable levels of indicator organisms, not always associated with rainfall events (Robertson 1998). The survey examined the microbiology of nearshore beach water quality after three rainfall events of between 11 and 15 mm, and found indicator levels per 100 mL of 4500–8000 faecal coliforms and 800–64 000 faecal streptococci; however, the source of the microbiological contamination was unclear.

The density of septic systems is thought to be one of the most important factors influencing groundwater contamination. Catchment-scale studies have recorded contamination in unconfined aquifers where the density of on-site systems exceeds 15/km^2 (Hoxley & Dudding 1994; Yates 1985). While Gardner *et al*. (1997) also made recommendations on sustainable density, the degree to which contamination is acceptable appears to depend on the beneficial long-term use of the aquifer, given that contamination, particularly by nitrate, is likely.

Study methodology

The desk study comprised a collation and review of available geological, topographical, hydrogeological and water-quality data. Relevant data on bores and wells in the area were also gathered from Tasmanian Department of Mines records.

The field investigation involved locating and visiting some 26 bores and wells in the study area. In discussion with property owners, information on bore history, performance and water quality was gathered and recorded on a database. Where possible, bores were sampled and tested for a number of physical, chemical and microbiological water quality parameters.

Water-quality parameters

Some water-quality parameters were tested at the time of sampling, others during later analysis but always within 24 hours of collection. Water samples for chemical analysis were collected in clean polyethylene bottles after approximately five minutes of continuous pumping. Microbiological samples were collected in sterile glass bottles according to standard procedures and transported to a testing laboratory within 24 hours. On several occasions, shallow wells without pumps had to be sampled with hand bailers. The same procedures were followed for these samples as for the pumped bore samples.

Water-quality parameters tested in the field were pH, electrical conductivity, turbidity and temperature. Samples from each location were later analysed for nitrate (NO_3^-) using the Cadmium Reduction Method and a HACH DR/2000 spectrophotometer. Microbiological analysis for faecal coliforms and *Escherichia coli* was conducted by the Public Health Laboratory at the Royal Hobart Hospital, Hobart.

RESULTS

Desk study

The study area is largely underlain by Triassic sandstone, comprising well-bedded quartzitic sandstone with minor mudstone horizons. These have been intruded by Jurassic dolerite that is more resistant to weathering and hence forms headlands such as Tiger Head and Spectacle Head. The gently sloping coastal plain is draped with a mantle of Quaternary windblown sand. One borehole located approximately 1 km east of Valleyfield Hill indicated a thickness of 11 m of Quaternary sands.

Vegetation-stabilised sand dunes are apparent in the Quaternary deposits in the Tiger Head Beach and Okines Beach area immediately to the north. The dunes are oriented parallel to Carlton Beach and reflect the prevailing wind direction in Quaternary times. Recent river alluvium and spit deposits occur along Carlton, Red Ochre, Tiger Head and Okines Beaches.

The soils of the area reflect the underlying geology and the drainage regime. Deep sandy soils occur on the recent windblown deposits. Podzols, comprising a deep sand horizon with an iron or humus accumulation at depth over

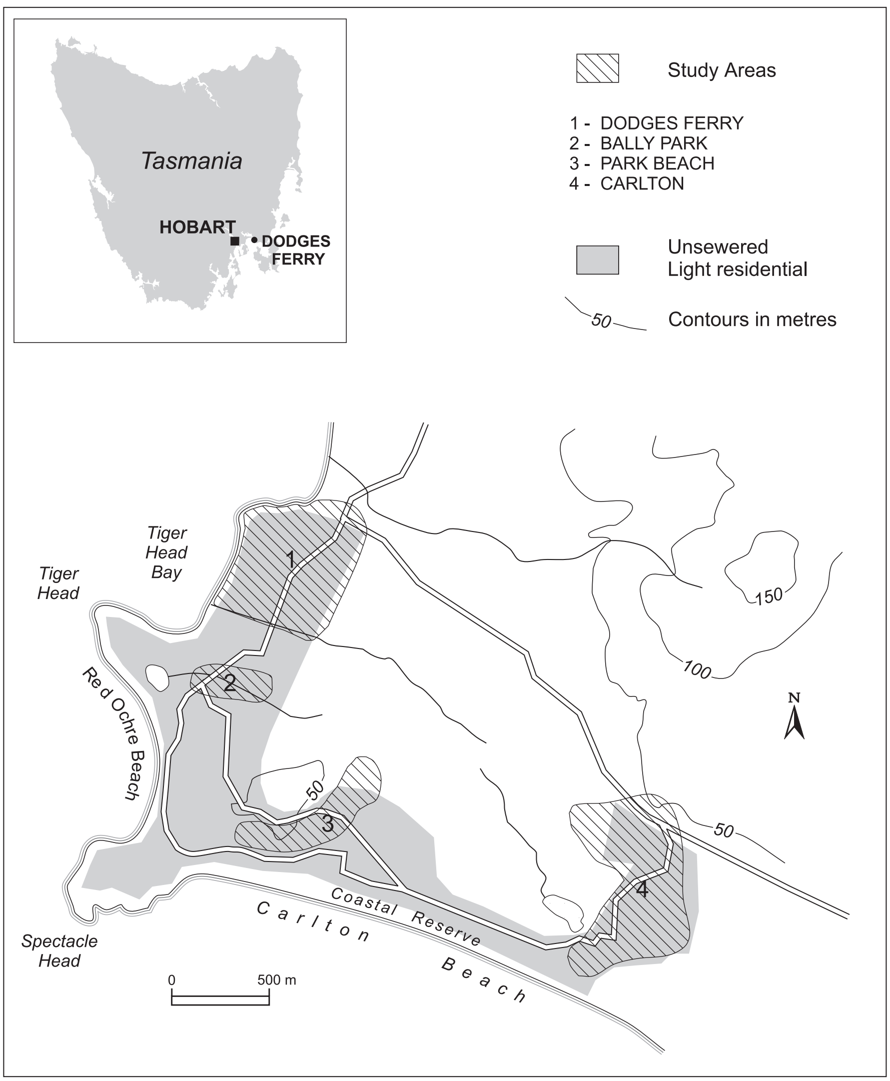

Figure 1 Location of study areas.

clay, develop on the Triassic sandstone. More clayey soils develop on dolerite. In areas of poor drainage, such as the lagoon area behind Carlton Beach and the low lying area inland from Okines Beach, the soils are typically clayey.

Data from available bore records indicate that, in some coastal areas of Dodges Ferry and Carlton Beach, spear-point bores access a shallow aquifer at depths of only a few metres. This aquifer is of variable depth and yield, reflecting the thickness of the windblown sands. Some bore users indicate that yield diminishes in drier periods.

A deeper aquifer exists in the Triassic sandstone, where bores 30–60 m deep access more saline waters. In places bores penetrate the Quaternary sands to intersect this aquifer, but on higher ground there is only a veneer of superficial deposits over the sandstone.

Field results

The broad distribution of bores in the study area is indicated on Figure 1 (individual locations are not identified at this stage because of the need for confidentiality). Groundwater samples were taken over a three-day period in February 1998 at 26 bores and wells located within the study area. Water-quality data collected are presented in Table 1.

DISCUSSION

Geology

The windblown Quaternary sands define the areas of shallow and often perched aquifers. Immediately below the unconsolidated sands the upper horizons of the Triassic sandstone are weathered to depths of some metres. This sandstone extends under most of the area, but in places is intruded by igneous sills. Jointing in the sandstone, the presence of shale horizons and the igneous intrusions all affect transmissivity, and are commonly noted in borehole logs at about the depths at which high yields occur.

Hydrogeology

Unconfined shallow aquifers in the Quaternary windblown sand deposits recharge from rainfall and surface waters, and hence are susceptible to contamination from a number of sources. Amongst these are poorly performing septic trenches, particularly if overloaded at peak summer periods, or if inundated by heavy rain, or where sited close together.

The deeper sandstone aquifer is less variable in yield but is appreciably more saline than the shallow sands. This fractured-rock aquifer provides a plentiful supply for some bores, but usage is limited to toilet flushing, occasional laundry use and for garden watering of salt-tolerant plants.

Table 1 Groundwater quality data.

	Bore depth (m)	pH	Elec. conductivity (μS/cm)	Turbidity (NTU)	Temperature (°C)	NO_3^- (mg/L)	Faecal coliforms (cfu/100 mL)	*E. coli* (cfu/100 mL)
Area 1 Dodges Ferry								
1	60	7.32	4220	1	16.8	<0.44	<2	<2
2	54	7.18	3430	0	16.1	<0.44	<2	<2
5	14	6.98	2300	0	17.2	253	<2	<2
6	–	6.34	5860	0	16.8	50.6	<2	<2
9	–	6.67	2290	0	18.0	30.8	<2	<2
15	36	5.51	410	81	19.5	46.2	<2	<2
23	30	6.30	4600	0	16.7	1.32	<2	<2
32	–	6.52	1400	14	16.2	14.1	<2	<2
Area 2 Bally Park								
7	–	4.77	13600	350	16.0	0.88	<2	<2
Area 3 Park Beach								
22	9	6.51	1170	83	15.2	6.6	<2	<2
24	41	6.48	2400	0	15.4	1.76	<2	<2
25	8	6.43	1380	10	14.7	9.7	<2	<2
26	–	6.51	1130	11	19.5	4.0	<2	<2
27	40	5.25	11300	59	15.2	4.4	<2	<2
28	90	4.48	10500	0	17.5	3.1	<2	<2
29	–	6.56	1350	52	15.5	3.5	<2	<2
Area 4 Carlton								
10	40	6.62	1940	0	15.6	0.44	<2	<2
11	–	6.04	2030	10	14.7	7.9	<2	<2
12	4	6.71	1930	10	16.0	19.8	12 (est)	12 (est)
13	–	6.16	2440	0	15.1	2.2	<2	<2
14	60	6.37	920	0	14.4	2.2	<2	<2
17	–	5.60	1310	0	16.6	0.44	<2	<2
18	30	5.82	1750	0	15.5	0.88	<2	<2
19	60	6.92	3920	0	15.3	0.44	<2	<2
20	65	5.70	3080	0	16.6	0.44	<2	<2
21	19	5.40	2860	0	16.9	0.44	<2	<2

Occasional seeps and springs were noted, in particular along the coast, where clay horizons support perched water tables. There is evidence that overpumping in bores close to the coast causes saltwater ingress and deterioration of water quality with time.

Water-quality results

In the interpretation of quality data, the proposed use of the water should be considered. Water obtained from bores and wells in the Dodges Ferry area is not used for potable purposes, but primarily for irrigation. However, there is a risk that, on occasions, people will come in contact with the groundwater. It is therefore appropriate that the water quality be examined in relation to criteria for potable uses (National Health & Medical Research Council/Agriculture & Resource Management Council of Australia and New Zealand 1996).

The quality of samples collected is variable, due to the aquifer depth and groundwater residence time in the material. The most obvious feature of the groundwater is the high electrical conductivity (salinity) of some of the samples. While there are no health effects associated with high salt concentrations, taste determines whether it is acceptable, and these salinities may make the groundwater unfit for irrigation. Only one sample met the criteria of Class 2 (medium salinity water: Environment Protection Authority 1983), with the majority in Classes 3 and 4 (high and very high salinity water, respectively). Four samples (Sites 6, 7, 27 and 28) could be classified as extremely high salinity water which would kill vegetation and this was confirmed by residents at these sites.

The pH for drinking water should be between 6.5 and 8.5 (National Health and Medical Research Council 1996). Lower pH values are to be expected for groundwaters and this is in fact the case for most of the samples. Several of the samples have pH values less than 6.0, and two samples (Sites 7 and 28) have values between 4.0 and 5.0. These waters would be corrosive under certain circumstances.

The turbidity of most samples was also low, as expected. These waters are typically clear, containing no suspended matter when collected. However one sample (at Site 7) recorded a high turbidity, which is unusual given its high salinity. Some waters, particularly those sampled from shallow wells (Sites 11, 12, 13, 25, 26 and 29) were lightly coloured, presumably from the leaching of soil organic matter, while two samples (Sites 6 and 15) were highly coloured. Some samples were odorous, indicating low dissolved oxygen concentrations (Sites 11, 12, 13 and 22).

As mentioned previously, the presence of nitrate in groundwaters can indicate contamination by sewage. Prior to this investigation, concern had been expressed that failing on-site systems may be contributing to groundwater contamination. The most obvious indicators of failing systems are usually the presence of odorous, black organic seeps and saturated ground. This is more common during winter in the Dodges Ferry area, although one seep was noted at one beach in this study during the dry summer months.

Given the porous nature of the sediments in the area, it is logical to assume that effluent may reach the shallow aquifers when systems fail. The water samples which were collected from bores and wells were therefore analysed for nitrate (NO_3^-) as an indicator of the presence of human waste. Aerobic activity in unsaturated soils results in the almost total conversion of ammonium in human wastewater to nitrate. This ion is highly mobile due to its solubility and low adsorption capacity.

The majority of bore waters exhibited low or background concentrations of nitrate. Higher nitrate levels were recorded at a number of sites, usually associated with clusters of residences. One sample (Site 5) contained 253 mg/L, which is a very high concentration by any standards. This sample was from a shallow well approximately 14 m deep, above which was sited the septic system. The water sample was contaminated by effluent which may have reached the aquifer by percolation through the porous media or by leakage down the side of the casing.

The water sample collected at Site 6 also exceeded NH&MRC/ARMCANZ Drinking Water Guideline of 11.3 mg/L nitrate–N (50 mg/L nitrate). Other above-background nitrate levels were recorded at Sites 9, 11, 12, 15, 22, 25 and 32. Testing undertaken by Sorell Council also indicated high concentrations at Site 6 (twice) and Site 9 (once). These higher than background concentrations appear to be associated with the shallower bores.

Coliform organisms are also used as indicators of faecal contamination of water supplies. The test results for this study for faecal coliforms and *Escherichia coli* are shown in Table 1. At all locations except Site 12 the samples contained less than 2 cfu/100 mL for both bacteriological indicators. These results indicate that the organisms were not found according to the method of detection for all sites, with the exception of Site 12 where an estimate of 12 cfu/100 mL is given. At this site a shallow (4 m) well was sampled in which the water was highly coloured and odorous. A higher than background nitrate concentration was also recorded for this sample.

Of interest is the fact that high numbers of the bacteriological indicators were not recorded at the sites with the highest nitrate concentrations (Sites 5, 6, 9 and 15). The use of pathogens as indicators in groundwaters is somewhat problematic in deep bores, due to the substantial residence time of such waters and the potential for bacterial die-off. *E. coli* has also been recorded at one shallow site (Site 26), according to the test results obtained by Sorell Council. On the basis of these results, bacterial contamination of groundwaters is not regarded as a serious problem.

CONCLUSIONS

The preliminary testing has indicated that there are several areas at risk of groundwater pollution from failing on-site systems in the Dodges Ferry area. It is not yet possible to quantify the risk, but there appears to be a connection between shallow groundwater quality in specific areas and wastewater disposal, particularly where houses are close together.

One such area is near the surface drainage divide between the Third Avenue/Jetty Road catchments at Dodges Ferry (Sites 5, 6, 9, 15 and 32). The possibility of groundwater contamination here is also supported by data collected by Sorell Council. There is a high density of small lot residences and the groundwater samples here contained the highest nitrate concentrations.

Significantly lower (but above background) nitrate concentrations were recorded from bores in the Gully Road catchment at Carlton (Sites 22, 25 and 26). Shallow groundwaters in this area appeared to be coloured with particularly high iron concentrations. The third cluster of residences is further along Carlton Beach in the Lloyd/Meethanar Street catchment (Sites 11, 12 and 13). Here shallow groundwater at Site 12 contains bacteria and nitrate, is highly coloured and sometimes odorous.

The other bores sampled from the more elevated areas in the Dodges Ferry area did not indicate any contamination or groundwater-quality problems, other than high salinity. This is dependent upon the local geology, rather than waste-disposal practices. It does appear that both surface and subsurface drainage is towards each of the three clusters where elevated concentrations were recorded. They are all located at the bottom of drainage areas and the catchments above them each contain high densities of on-site systems.

In this study a limited number of representative samples have been collected. The results appear to show a connection between the shallow aquifer quality, the number of residences and their domestic wastewater-disposal practices. However the quantification of risk to the community is difficult, since the groundwater is not used for potable purposes. Clearly the density of on-site systems, house occupancy and number of residents have a bearing on the potential for groundwater contamination. Further groundwater and stormwater sampling and analysis, particularly under wetter conditions, is required.

In the Dodges Ferry area there are many vacant lots whose future development with on-site wastewater disposal will increase the potential for groundwater degradation. It is important that existing guidelines be enforced and that developers be afforded technical support for system installation and maintenance. As a result of this study and the introduction of new codes regulating on-site systems, the Sorell Council intends working toward a longer term planning framework to protect groundwater quality in the Dodges Ferry area.

While concern has been expressed that high densities of on-site wastewater systems (15/km^2 or more) might contribute to groundwater contamination, few studies have substantiated this. There is a clear need for further studies to clarify the picture in other parts of Australia.

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